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ABSTRACT

In spite of the widespread implementation of Writing Across the Curriculum (WAC), there remains little concrete evidence of the writing-thinking connection. This paper proposes a new research method that tracks students' performance and production at a deeper level of specificity than that in previous investigations of this relationship, e.g., in process studies. The method involves comparative text analyses of students' drafts along key conceptual dimensions as measured through their linguistic indicators (reference, syntax, modality). In the past, linguistic indicators have often been treated as isolated sentence-level errors. In contrast, the proposed analytical method--based on emergentist/connectionist approaches in the cognitive sciences--shows how these elements function in concert to demonstrate student's developmental paths. The results were obtained from freshman writing-mathematics course clusters emphasizing revision in academic and professional writing. Assignments included feasibility studies on identification number systems and research papers proposing mathematical solutions to real-world problems. Text analyses were conducted of all drafts generated, yielding detailed profiles of individual student's difficulties at each phase of the writing and conceptualizing process. Contains 38 references, and 6 tables and 4 charts of data. (Author/RS)

AN EMERGENTIST MODEL
FOR WRITING IN MATHEMATICS

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In spite of the widespread implementation of Writing Across the Curriculum (WAC), there remains little concrete evidence of the writing-thinking connection. This paper proposes a new research method that tracks students' performance and production at a deeper level of specificity than that in previous investigations of this relationship, e.g., in process studies. The method involves comparative text analyses of students' drafts along key conceptual dimensions as measured through their linguistic indicators (reference, syntax, modality). In the past, linguistic indicators have often been treated as isolated sentence-level errors. In contrast, the proposed analytical method--based on emergentist/connectionist approaches in the cognitive sciences--shows how these elements function in concert to demonstrate student's developmental paths.

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INTRODUCTION

Even though writing-across-the curriculum (WAC) and writing-to-learn (WTL) programs have been established for more than 30 years now, the movement continues to be plagued by questions about the validity of its professed writing-thinking link (Applebee, 1984; McLeod & Maimon, 2000).

Studies on WAC have also been criticized as being mainly "discursive and testimonial, lacking the sort of carefully designed research which might lend support to the movement" (Anson, 1988, p.2). As a consequence, instructors teaching in the disciplines still hesitate to incorporate WAC and WTL components in their courses. And when they do, informal writing is the norm. For example, in the field of mathematics education, even a cursory survey shows that informal writing predominates, with common assignments being journal writing (Nahrgang & Petersen, 1986; Burkam, 1990; Buerk, 1990; Mayer & Hillman, 1996), multiple-entry logs (Powell, 1997), free writing (Elliot, 1996), and impromptu writing (Miller, 1991). As one mathematics instructor confesses:

> Formal writing remains a difficult task for most of us (and I include myself in that group). One must be clear and concise, with prescribed goals to be worked toward and achieved.
>
> (Burkam, 1990, p. 119)

An Emergentist Model

As with previous researchers exploring the relationship between writing and thinking, we regard the text as composed of traces of the process that created it (e.g., Cooper & Odell, 1977; Cooper & Odell, 1999). To discover what these traces are and what they represent, we need to get down to the particular and the concrete, to analyze the text at the micro level, breaking it down into its linguistic elements. Unfortunately, no analytical method in the field of composition research currently exists that can actually meet the criteria of linking these together collectively: students' linguistic and cognitive structures, their writing product and process, their performance at different stages of writing, and qualitative and quantitative data. To do so, we need to go beyond previous attempts at drawing the writing-thinking connection in composition study.

One area in the cognitive sciences that is relevant to the issue at hand involves recent work on emergent linguistic and knowledge structures in development. These initiatives, covering a wide spectrum of specialized areas, are being conducted within the new paradigm of emergentism (see MacWhinney, 1999). Generally, emergentist accounts explain how the organism follows certain developmental pathways--so much so that universal patterns may be discerned--through the interaction of biological and environmental forces. At this early stage, emergentist accounts have only been concerned with lower order functions such as phonological processing (Browman & Goldstein, 1989; Maddieson, 1997), word reading (Seidenberg & McClelland, 1989), grammaticality judgments (Allen & Seidenberg, 1999), and noun learning (Smith, 1999). The emergentist framework accounting for development in precise, mechanistic terms includes connectionist models adopted from work in neuroscience (see Elman et al., 1999).

In this paper, we will adopt the concepts of emergentism and connectionism to account for writing development. *Emergentism* as used here refers to the appearance that groups of students seemingly follow discernible pathways of development in their writing. These pathways assume particular group tendencies owing to the interplay of linguistic-cognitive constraints and the parameters of the learning environment. Individual forces (e.g., motivation, affective states, students' background), of course, are also at play in each student's development. However, an emergentist account concerns itself with universal patterns rather than individual idiosyncracies. It is the former that has applicability to other student populations and settings.

Connectionist models were first constructed to simulate mental processes by replicating brain architecture, i.e., through the use of massively parallel networks connecting myriads of cells (Feldman, 1985). The concept of *connectionism* is useful to our investigation here because it allows us to see coherence in the microelements of a text, and through its various phases of development, by using myriads of connections among the elements to uncover emergent patterns in students' writing. Our interest here is not simply with the identification of emergent patterns but with the explanation for their occurrence. Answering the question as to where the particular language feature "comes from" is the hallmark of emergentist study (MacWhinney, 1999).

Our proposed emergentist model involves microtextual analysis of the whole corpus of students' drafts so that we may obtain detailed linguistic-cognitive profiles of their production-performance at different stages of writing. This paper illustrates the model's application in a writing-in-mathematics setting that emphasizes formal writing, defined here as the type of writing that follows standard academic conventions for the discussion of abstract, technical topics. Formal writing relies heavily on carefully structured, stable organizational frameworks and subordinative syntactic relations to interconnect the elements under discussion. It is guided by such principles as logical order, coherence, precision, clarity, and consistency. Formal writing is distinguished from casual, personal, conversational expression. Using papers from one specific content area, especially in a context that is both linguistically and conceptually demanding, allows for unambiguous presentation of this model.

METHOD

This section consists of two subsections. The first provides pertinent background information on the classroom setting from which the data were gathered. The second describes the research method used.

Classroom Setting

Writing-Mathematics Course Cluster

An introductory mathematics course for non-Mathematics majors, *Excursions in Mathematics*, was linked to a freshman composition class, *College Writing I*, at Marist College, New York, in the fall of 1998. The same group of freshmen attended both classes, with the writing and mathematics instructors observing and participating in each other's sessions throughout the semester. The mathematics course focused on the topic of check digit schemes, which are mathematical methods used to detect errors in the transmission of identification numbers. As the semester progressed, the mathematics course introduced increasingly sophisticated check digit schemes. The courses were integrated at multiple levels in terms of thinking strategies (e.g., defining, comparing, analyzing), topics (e.g., symmetry), and assignments.

Subjects

Enrollees in this cluster were all freshmen with undecided majors. Thirteen subjects were selected randomly from this cluster. Of the 13 subjects, five were female. The subjects' grade point averages ranged from 3.4 to 1.66 for that semester. They received course grades ranging from "A" to "D" in the composition class. The students were labelled in this study as Subjects A-M.

Writing Assignments

All take-home writing assignments were based on mathematical knowledge acquired from the *Excursions in Mathematics* class. All the assignments required application of skills and knowledge gained in the two courses cumulatively. The assignments were a definition paper on check digit schemes, a summary of the number theoretic techniques applied to check digit schemes, a paper proposing the development of a new cipher, a formal report on data analysis, a feasibility study recommending a check digit scheme for implementation at an organization, and a research paper employing mathematics to solve a real-world problem (e.g., creation of a universal medical identification number system).

The students were encouraged to revise all papers. All of them submitted at least one revision of each paper, with a few turning in as many as four or five rewrites for some papers. All papers were returned to the students with copious notes from both instructors. Instructors' feedback was comprehensive, covering problems with coherence, organization, audience and purpose, clarity, precision, informativity, language, mechanics and grammar. This was necessary owing to the high demands on the students: the assignments required formal writing on a mathematical topic that was initially unfamiliar to them. In addition, with the exception of the summary paper, all assignments required reconstruction, synthesis, and application of new mathematical knowledge.

The writing-in-mathematics papers (original and revised drafts) collected from the subjects formed the linguistic corpus for this study. A total of 188 drafts were analyzed.

Research Method

To illustrate how an emergentist account may be used to illuminate writing development in this WAC context, a sample of four measures was selected: reference, syntax, modality, and representation. (See section below for definitions.) To determine the students' ability to deal with formal writing (defined above as involving the construction of stable frameworks), reference was incorporated as one of the measures. To explore the connection between language and thinking, the students' ability to maintain the complicated, hierarchical syntactic structures of formal writing (as the mathematical concepts they had to deal with became increasingly difficult) was investigated. Thus, the second measure considered was syntax. Because we are dealing with writing in mathematics here, the students' ability to handle probability, range of possibilities, and hypothetical situations was also analyzed. These were captured in the modality measure. Typical of students' problems in mathematics is their inability to deal with symbolic representations with dexterity, to elaborate on and exemplify them. This was labelled as the representation measure. Collectively, reference, syntax, modality, and representation serve to demonstrate how students' mathematical understanding developed in the writing process. Owing to the scope of the paper, only sample indicators of each measure are represented here.

Qualitative Analysis

The analytical method targeted areas of difficulty on the four measures in each draft of the corpus. Comparative analysis (inter-draft, inter-student) helped bring into sharper focus the patterns of problems common to certain individuals and subgroups.

Reference

Reference is an essential feature to examine in formal writing because creating a text often involves constructing a discursive space where the elements mentioned are situated in a defined framework, their interrelationships carefully traced, and any shifts clearly signalled. (See, for example, Givón, 1993 on this topic.) Though a vital factor to consider in microtextual analysis, referential elements are so common--such as the article the--that they are easily overlooked. But it does matter whether a student wrote *a* check digit scheme or *the* check digit scheme. If she started out the discussion with the definite article without an antecedent, which particular one out of all the check digit schemes available was she referring to? Or did she not realize that there was more than one existing scheme?

We were interested, therefore, in finding out whether the subjects could create a conceptual framework to situate elements to be discussed, remaining consistent in references to these elements and signalling clearly movements in the level of abstraction. Owing to the scope of this study, referential indicators were confined to common ones such as the misuse of articles (e.g., when the student was unsure about the status of the referent or when the student had yet to construct a stable and coherent framework for the topic discussed), pronoun-antecedent mismatches, and unintended shifts in pronouns causing unsettling switches in the frame of reference. (See below for examples of these indicators from the data.)

Syntax

The syntax of student writers has been studied in the field of composition research (e.g., Hunt, 1977; Moffett, 1992; Strong, 1999), but our concern here is not with syntactic complexity in writing acquisition. More pertinent to the present investigation, therefore, are classic studies in orality and literacy research, where it has been established that formal written language is subordinative, dense with information, and rigidly structured whereas speech is loosely formed, with "fuzzy boundaries" (Beaugrande, 1984, p. 257) and information strung up like "beads on a frame" (Bernstein, 1974, p. 134). The production of written language thus places undue burden on the writer--unless he is adept at employing the technology of writing (Ong, 1982). With the freshmen in this study, we were interested in determining whether their writing broke down syntactically under cognitive pressure. It has long been recognized that this does indeed happen with student writers faced with cognitively demanding tasks (Nielson, 1979; Schwalm, 1985).

Next, we were curious about what forms these syntactic breakdowns took. It has been widely reported in the field of basic writing that students' language resembles more closely the looser forms of speech than the tight syntactic structures of writing (Krishna, 1975; Carkeet, 1977; Shaughnessy, 1977; Beaugrande 1984). Although none of the subjects in this study was placed in remedial writing, we nevertheless investigated if cognitive pressures induced them to fall back upon the oral mode, their primary medium of communication.

Based on knowledge gained from research in basic writing, and in literacy and orality, the corpus was examined for the following kinds of syntactic breakdowns.

Sentential strings

Sentential strings are defined here as loosely connected phrases substituting for sentences, where the phrases/clauses do not stand in clear syntactic relations with each other. They are called "strings" here because they lack the hierarchical structuring of formal written language. Included in this category are so-called "run-on sentences" in composition study, "blends" (Carkeet, 1977) or "blurred patterns" (Shaughnessy, 1977) in basic writing, and "clausal complexes" (Kress, 1982) in writing acquisition research. Excluded from analysis were mere punctuation errors. This was done by painstakingly comparing all drafts by the subject in question to ensure that these features did indeed form patterns of problems clustering around discussions on unfamiliar mathematical concepts. These patterns were contrasted against sentences discussing simpler or familiar topics.

Discourse topics

Discourse topics are fragments (e.g., phrases or parts of clauses) preceding subjects of sentences. They have been discussed at length in studies on discursive functions of language (Chafe, 1976), speech in social settings (Wolfram & Fasold, 1974), and pre-sentential forms (Givón, 1979). In student writing, the fragment serves the purpose of announcing the topic of the sentence and/or of providing cohesion (Shaughnessy, 1977; Kress, 1982).

Equivalency

Loosely strung-together "sentences" may rely preponderantly on a generic verb such as the identificational *be* instead of more concrete verbs requiring careful selection. This can then lead to problems of syntactic and semantic equivalence between the subject and the object, which a formal sentence demands.

Modality

It was anticipated that there would be problems with modality in this study, especially for the weaker students writing on a content area generating some degree of anxiety. Modality is defined here as the coding of the writer's attitude regarding the truthfulness of the proposition

(Frawley, 1992). Modality devices thus signal the gap between the proposition and the reality as perceived by the writer. Modality represents a crucial factor in mathematics because of the discipline's emphasis on possibility and comprehensiveness. Problems might occur, for example, if the student failed to distinguish between the hypothetical and the real, to comprehend that the case presented was not the only one, or to appreciate the full range of possibilities. For instance, the following pair of sentences differ in terms of modality: check digits *can* appear at the end of identification numbers vs. check digits appear at the end of identification numbers. The first sentence implies the existence of types of check digits other than the one expressed in the proposition; the second allows for only the one expressed. Indicators of modality in this study were confined to modal verbs and adverbials. Other aspects of modality not central to writing in mathematics, such as obligation (deotic modality) were not considered.

Representation

In probing students' thinking processes when writing on mathematics, it is crucial that we consider their ability to deal with symbolic representations. Could the student go beyond merely reproducing mathematical equations? Could she explain what the variables represented? Or could she apply a formula to a real-world problem? Two measures of representation were considered here: the absence/presence of illustration and explanation as they pertained to symbolic representations. We then examined if these were integrated into the subjects' texts.

Quantitative Analysis

All 188 drafts in the corpus were coded by a research assistant trained in microtextual analysis and by the first author separately. Inter-coder agreement for the selected features was

95% for the whole corpus. Where a disagreement was registered, a third coder was used to resolve the discrepancy. For each subject, the frequency of problems with each measure (reference, syntax, modality, and representation) was tabulated for all drafts of all papers. Because the number of submissions varied from student to student, the corpus was first divided into first, second, and third drafts. The number of subjects submitting fourth and fifth drafts was too small to be considered. Eight subjects produced up to three drafts per assignment while five stopped at two drafts.

From the coding undertaken, the frequency of each measure in each draft written by a subject was recorded. The frequency counts of each measure found in all drafts of a category (first, second, or third drafts) produced by a subject were all added together to obtain that student's total frequency for that measure. The total frequency was divided by the number of drafts in that category handed in by the subject to obtain that student's average frequency of each measure. In other words, the *average frequency of each measure* indicates how often problems of that particular measure appeared in each draft of that category for the subject in question. For each subject, the *total average frequency of all measures* was obtained by adding up all four average frequencies calculated in the manner specified above. The total average frequency of all measures thus indicates how often problems of all four measures occurred in each draft for that category.

RESULTS

This section first presents the qualitative results of the microtextual analysis of students' drafts. Sample excerpts are shown for each measure. Next, quantitative data are displayed in graphical and tabular form.

Qualitative Analysis

Reference

To illustrate what referential problems in the corpus looked like, an excerpt is reproduced at length:

> A check digit scheme is a system of identification that allows numbers to be transmitted when scanned without errors. The check digit is a number at the end of an UPC or ISBC code that is the sum of all of the other numbers.
>
> These check digit numbers are used to identify individual items, specific products, persons or accounts. If the check digit number is not matched correctly with the others then the item with the code is wrong. This is used to find packages that have been shipped to a wrong location or to distinguish counterfeit money from real money.
>
> This system is made up of a few different parts. All of the numbers work together to create the check digit system; check digits are used in a variety of places such as license plates, books, packages and money. When referring to an identification number, two things are needed: the number of digits or letters in the number and the position of each letter or digit... (I, Definition 1, pr1s1-pr3s3)

[Note: The transcription label in parentheses displays the writer (Subject I), type of assignment (definition paper), draft number (1), and position of the excerpt in the original text (paragraph 1 sentence 1 to paragraph 3 sentence 3). In this study, all students' samples are reproduced with errors left uncorrected.]

Focusing only on referential problems in the above excerpt, we notice the following characteristics. In paragraph 1, the relationship between <u>check digit scheme</u> and <u>UPC or ISBC code</u> [sic] is not established, nor is it apparent what <u>all of the other numbers</u> referred to.

Paragraph 2 then begins with another referential problem: These check digit numbers does not have the right antecedent in the preceding paragraph. Moreover, paragraph 2 sentence 1 switches to a more general level of discussion by giving a range of uses (to identify individual items, specific products, persons or accounts) whereas the preceding sentence ending paragraph 1 narrows the choices to two sooner than expected. In paragraph 2 sentence 2, the definite article is used repeatedly without clear antecedents (the others, the item, the code). The last sentence of paragraph 2 is similarly problematic. The demonstrative pronoun This presumably refers to the check digit scheme, which the preceding sentence describes but never identifies overtly. These referential problems continue into paragraph 3, which lacks definite antecedents for This system (pr3s1) and All of the numbers (pr3s2). Again, the discussion returns to a general level, mentioning a range of uses (license plates, books, packages and money) with no attempt to tie it to paragraph 2 sentence 1 of the same type. Then, the concept of identification number crops up with the indefinite article late in paragraph 3 sentence 3--whereas its relationship to check digit scheme should have been laid out explicitly earlier. At this late stage in the discussion, there exists now a mismatch between the reference to check digit scheme, which is now labelled with demonstrative pronouns, and the reference to identification number, which is still used with the non-specific indefinite article.

Ideally, Subject I should have drawn up a coherent framework in the introduction, laying out the definitions of check digit schemes, identification numbers, and check digits, simultaneously spelling out the relationships among them. Then he could proceed to describe possible uses and types of schemes, with the UPC and ISBN codes serving as examples. But the excerpt shows instead Subject I's difficulties in synthesizing the newly encountered information, in situating each piece solidly within a stable discursive space. The referential problems could not have been isolated mistakes; they formed distinctive patterns that were attributable to conceptual difficulties.

Since microtextual analysis enables us to compare drafts, let us turn to Subject I's revision to confirm the above findings:

> A check digit scheme is a system that enables numbers to be transmitted without error. The check digit is a number that is assigned to the end of a UPC or ISBN code that's the sum, or result of a modulo. This check digit system is made up of a few different parts, the group of numbers that identifies the item, and the check digit. All of the numbers of the system work together to create the check digit. Check digits are used in places such as books, packages, and even money.
>
> These identification numbers are used to identify individual items, specific products, persons or accounts. If the check digit is not matched correctly with the other numbers in the system, then the item with the I.D. or check digit will be wrong. This is used to find packages that have been shipped to a wrong location or to distinguish counterfeit money from real money. (I, Definition 2, pr1s1-pr2s3)

The old referential problems remaining notwithstanding, the sentence on the composition of check digit schemes in paragraph 3 in draft 1 has now migrated up to paragraph 1 to enable closer linkage with its subject (<u>A check digit scheme, This check digit system</u>). Additionally, the succeeding sentences now tie the check digit system more closely to its components: <u>This check digit system is made up of a few different parts, the group of numbers that identifies the item, and the check digit. All of the numbers of the system work together to create the check digit</u>. (pr1s3-4)) in draft 3 compared to <u>This system is made up of a few different parts. All of the numbers work together to create the check digit system...</u> (pr3s1-2) in draft 1.

The pattern of misused articles was not confined to Subject I alone, as the excerpt below testifies:

> The first set of numbers are the natural numbers. These numbers also called the counting numbers...The next set of numbers are called the whole numbers. The whole numbers are the same numbers in the set of natural numbers except the for the fact that the whole numbers ...After the whole numbers comes the integers...The next set of numbers are the rational numbers...The last set of numbers are the real numbers... (G, Summary 1, pr1s5-14)

Why did Subject G preface all these types of numbers with the definite article when the correct usage was without? Did he not comprehend that in each definition, the whole set was being referred to (hence natural numbers), not merely a subset (the natural numbers)?

With the same draft, we notice the sudden appearance of the second person in this discussion on abstract numbers, just when it became increasingly complicated:

> If a number is relatively prime it means that you have two integers and neither one of them is divisible by a number larger than one. (G, Summary 1, pr1s26)

Contrast that with an earlier sentence which remained in the abstract:

> A prime number is an integer that is greater than one where the only numbers that divide it are one and itself. (G, Summary 1, pr1s21)

The concept of relatively prime is more complex than prime number. This isolated incident of a sudden switch to the second person in a discussion on abstract numbers would have gone unnoticed were it not for the fact that movement towards direct address was observed in other subjects' papers with more severe consequences.

In the excerpt below, the student seemed to have trouble fixing his point of reference between the first, second, and third person:

> A number is relatively prime if both x and y have no positive integer above one that divides them. Using what we know we can do the division algorithm where your answer of the divided numbers is the quotient and the remainder is what is left over. By understanding this you can do modulo arithmetic where you let a number other than one represent a unit. (J, Summary 1, pr2s10-12)

The above discussion is thoroughly garbled. Subject J appeared to have trouble understanding the barrage of mathematical concepts just encountered and pulling them all together into a framework that spelt out their relationships. In place of such a frame of reference, he employed the definite article (the division algorithm, the divided numbers) as if the identity of the referents were recoverable from the context. Situation-based referents are characteristic of speech, whereas writing necessitates text-based antecedents (Givón, 1993). In the oral mode too, direct address using the second person is common (your answer, you can do, you let a number).

For confirmation, presented below is an excerpt where the constant switching of pronominals is even more pronounced:

> To encipher the message, the first party, lets call him John, would first find...This numerical value also has to be changed so that it's harder for individuals to decipher. That's when the formula ($X^3 + 3$). So in order to find the value of a letter, you plug in it's numerical equivalent into "X" and cube it, after you find that sum you add it to 3. Take this example, if I wanted to find the letter "P", I first take the numerical value (00016), next I plug the numerical value into the formula, thus getting the equation, $(00016)^3 + 3$

> and you come up with the answer of 04099. These steps would then be done to every letter in the message that John wanted to send. (F, Process 2, pr3s1-pr4s8)

The organizational and content problems in this excerpt were not that severe. Subject F could still lay out the process of encryption in an orderly fashion. Nevertheless, the switches in reference from third person at the beginning to second and first and back and forth before returning to third person all serve to indicate that the task was not altogether an easy one.

The same assignment yielded a similar pattern in another student's paper:

> In order to find n, Ross chooses any two prime numbers and multiplies them together. N=(7)(11) so N=77. Then to find m, he takes those same two prime numbers and puts them in the equation M=(p-1)(q-1). M=(7-1)(11-1) so M=60. In order to find r, Ross would take 60 and break it down into its two prime numbers, two squared, three and five. Since five is the highest number, take the next highest prime number and make it r. In this case r=7. To find the next letter, s, Ross then uses the equation (r)(s)=1(mod m). (H, Process 2, pr3s1-8)

Subject H dealt with a cipher (using R.S.A. public keys) more complicated than that of Subject J. He maintained good control over the discussion until the single slip into the imperative in sentence 6 ([you] <u>take the next highest prime number and make it r</u>).

Thus far, several excerpts have been reproduced, some at length, to demonstrate how microtextual analysis involving close comparison between drafts of different students functions to yield informative results on problem areas. Below, for contrast, is an excerpt scoring well on the reference measure. This segment shows logical progression from indefinite articles and pronouns to definite articles and pronouns (underlined below):

> ...a check digit scheme is usually appended to an identification number, however, it may be in any position in the sequence. For example, take this typical Vehicle Identification Number: 1G3HY53L5NH32699...each number and letter stands for something that is completely different than if any other number or letter...In this example, the <5> between the <L> and <N> is the check digit. (B, Definition 2, pr2s1-5)

Note how the student moved logically and gradually from the indefinite and general--thus covering the topic comprehensively--to the specific and concrete. In this way he demonstrated control over the content and its expression.

Syntax

Although none of the subjects was placed in remedial writing, the forms commonly reported in basic writing did crop up occasionally. These forms appeared mainly in the writing of weaker students who received D-F grades in most of their first drafts. Tellingly, the syntactic breakdowns occurred at critical junctures in their papers, as the samples below indicate.

All three types of syntactic breakdowns defined above showed up in the corpus. We begin with an example of sentential strings:

> A type of math called modulo has an idea of letting a number other than 1 represent a unit is used in many places. (K, Summary 1, pr4s1)

This sample demonstrates how Subject K grappled with the newly introduced concept of modulo arithmetic. The student in this first draft was unable to synthesize the pieces of information presented in the textbook on what this new concept entailed and how it may be applied. Difficulty understanding and expressing the concept of modulo arithmetic was observed with several students. Problems with modulo are apparent from excerpts presented elsewhere in this study.

Another pattern of sentential strings is provided in the following sample:

In order to find the check digit in a U.S. Postal money order the formula would be $(3,1,3,1,3,1,3,1,3,1,3,1)x(a_1,a_2,a_3,a_4,a_5,a_6,a_7,a_8,a_9,a_{10},a_{11})=0$ mod 10 must be used. (I, Comparison 1, pr3s3)

The sentence remained intact in draft 2 even though the mathematics instructor commented in the first draft, "Makes no sense given the first part of your sentence."

These examples of syntactic breakdowns could not have been accidental mistakes not only because they resisted revision but also because students' revisions often failed to obliterate them entirely. This is seen in the next excerpt, which contains a discourse topic. Note how it took several revisions before the sentences became syntactic to express concisely the relationships among "integer," "dividing evenly," and "remainder":

When dividing two integers it sometimes divides evenly and sometimes there is a remainder. (J, Summary 1, pr2s3)

--> When dividing two integers it sometimes divides evenly, which means there is no remainder. (J, Summary 2, pr2s3)

--> When two integers divide evenly there is no remainder. (J, Summary 4, pr2s1)

The topics are underlined above. The looser coordinate clause in the first draft was replaced by a subordinate clause in the second draft, but the discourse topic remained till the fourth draft.

Discourse topics appeared in the writing of other students as well:

The strength of each scheme in terms of errors it can detect, the U.S. Postal Money Orders check digit scheme is weak. (D, Comparison 1, pr3s1)

To an observer, it would have been simpler to have written "The U.S. Postal Money Order check digit scheme is weak in terms of the errors it can detect" instead of the convoluted sentence above. But discourse topics were invariably left hanging in pre-sentence positions for student writers trying to juggle several unfamiliar ideas at the same time. With the assignment above, Subject D had to describe two particular check digit schemes and evaluate them according to given criteria--all the while contending with mathematical concepts and operations foreign to him.

The last syntactic feature investigated involves equivalency problems, which took the following forms:

One possible scheme is to add up the numbers. (E, Definition 3, pr2s1)

Prime factorization is when you take a number... (E, Summary 2, pr1s7)

The sentences above function in the same way as discourse topics in that the subject-as-topic is announced first followed by the generic copula before the rest of the sentence is tagged on without close syntactic monitoring nor conceptual consolidation.

Even where equivalency violations had not occurred, the sentence could be awkward, again illustrating the student's struggle with the mathematics topic:

Modulo is the idea of dividing a number x by 2x and always getting the same remainder. (I, Summary 2, pr3s15)

As seen above with other students, the concept of modulo arithmetic was complicated for Subject I. In the sentence above, variables were thrown in inappropriately, incorrectly constraining the meaning of modulo to multiples of 2.

Modality

The subjects often presented hypothetical examples as the only real cases in early drafts, for example as seen in their use of the copula in place of modal verbs (would, could, might). This occurred especially with the definition of check digit schemes, where many students did not at first realize that the schemes could take a variety of forms and the check digits could assume any position. Subjects F, I, D, E, J, K, and M omitted to qualify their introductions of examples of check digit schemes with statements indicating that they were merely illustrations and not necessarily representative of the whole category. Worse, Subjects D, E, and K misrepresented the reality by simply stipulating that a series of digits was an identification number and that the last number in the series was the check digit. These early drafts thus raised a host of questions not immediately apparent to the writers: Why was the sequence 3476810 taken to be an identification number? Why was 0 assumed to be the check digit?

In the following series of excerpts, Subject F eventually learned to use modal verbs to expand on the range of possibilities not fully grasped at the beginning:

> They now have digit(s) on the end of each sequence that the computer or person can check. (F, Definition 1, pr3s3)
>
> --> [Concrete example now added.] The check digits do not need to be always put at the end they can be anywhere. For example, say the identification number was 67021200988, the check digit could be any number. It could be the nine. (F, Definition 3, pr1s12-14)

In contrast to draft 1, which simply stipulated that the check digit was at the end of the number sequence, the revised version added the qualification that it need not be in that particular position. Subject F's use of the modal verbs can and could reinforced this possibility.

Representation

Poor papers showed the lack of careful exposition through varying levels of abstraction. For example, formulas were inserted without any explanation as to what the variables stood for.

Or, students would reproduce charts in the textbook without any integration into their papers, as shown in the excerpt below:

> There are several types of errors that can occur when transmitting numbers. See chart for types of errors.
>
> | Error type | Form |
> |---|---|
> | Single digit error | a - b |
> | Transposition of adjacent digits | ab - ba |
> | Jump transposition | abc - cba |
> | Twin error | aa - bb |
>
> All this motivates the following problem: How to develop systems that recognize when identification numbers are transmitted incorrectly... (D, Definition 1, pr2s1-8)

The chart, which was merely reproduced from the textbook, was never explained, prompting the mathematics instructor to ask, "What are a, b, c?" The chart was immediately followed by another plagiarised section of the textbook. These sections were rearranged but never revised in subsequent drafts in spite of the instructors' repeated criticisms.

Below, a sample from a stronger writer shows careful control over the content:

> Encoding messages is a very important aspect of any top-secret communication...To encode a message, several things must be done. First, an exact cipher has to be made up, created or borrowed from some other cipher by the sender, Alice...Alice decides on a basic pattern known as a shift...She chooses a five-letter shift. As shown in table 1, A-->F, B-->G and so on. Then she assigns each letter of the alphabet a numeric value...Once this has been assigned, Alice is ready to move on to the next step.

> The message Alice wants to send is "Hi Bob"...Now that these letters are translated up by five, Alice now can put a numeric value on the letters. M goes to 32, N to 33, and so on as shown ...The new message now reads...
>
> The importance of a cipher code that can be transmitted to two or more people without the use of a code that has to be publicly displayed is very important...
>
> (B, Process 2, pr1s1-pr5s1)

This subject started with a general statement on the topic before moving gradually into the specifics. Where illustration was used (table 1), he was careful to integrate it into his text, providing concrete examples along the way. He concluded the description by returning to the general discussion at the introduction.

Quantitative Analysis

To best present the quantitative results, the subjects were divided into three groups based on the patterns exhibited in their frequency counts for the given measures. The first group, labelled here as Group A, consisted of Subjects A, L, B, and G. The second group (Group B) comprised Subjects J, C, F, M, and H. The third, Group C, included Subjects D, E, I, and K.

Group A

The drafts of Group A students displayed low frequencies of problems on the given indicators. Total average frequencies of all four problems ranged from 2.2 to 3.5 for each first draft, and 1.1 to 2.2 for the second draft. (See Table 1.) More importantly, all four measures showed drops in revisions. The only exception was the reference frequencies of Subject A, which inched up slightly from 0.4 in first drafts to 0.6 in second drafts (Table 2). Even so, the pattern of constant decline in the frequencies of the linguistic-cognitive problems considered was apparent, as shown in Chart A.

Group B

Total average frequencies of all measures for Group B was higher, ranging from 3.4-6.7 in first drafts to 1.9-5.7 in second drafts. (See Table 3.) Like Group A, the average frequencies of all measures also dropped in revisions for Group B. However, when each measure was considered separately, great inconsistencies not seen in the graphs of Group A students showed up here. The reference and syntax measures of three students from Group B are shown in Charts B and C to illustrate the pattern. (See also Table 4 for average frequencies of each measure.)

Of these three students selected randomly from Group B, only Subject C followed Group A's pattern of decreasing frequency of referential problems. (See Chart B.) Subject F encountered increasing problems with reference in his second drafts before reducing them in his third drafts. Subject J's referential problems followed Subject F's pattern but at higher frequencies.

Taking the same three students, let us now examine the frequency of syntactic problems as shown in Chart C. This time, Subject C's syntactic problems shot up sharply in her third drafts. Subject F again experienced a drop in the frequency of syntactic problems in his third drafts following an increase in his second drafts. Subject J's syntactic problems were more pronounced in his third drafts than in earlier drafts.

Hence, even though a student in Group B might see decreasing frequency on a certain measure, on the whole, it is this kind of inconsistency that sets this group apart from Group A.

The increases in these measures indicate linguistic-cognitive difficulties faced by these students as they dealt with the pressure of revealing more of what they did or did not know in their revisions.

Group C

For Group C, the occurrence of problems examined was on the high end: the total average frequencies of all measures ranged from 4.6-8.9 in first drafts and 3.6-4.5 in second drafts. (See Table 5.) In addition to the pattern of fluctuating frequencies as seen in Group B's revisions, Group C experienced increasing problems with modality (Chart D). (See also Table 6 for average frequencies of each measure.) The only exception was Subject K, who experienced decreases in the frequencies of all measures in his revisions. However, the frequency counts in his first drafts were high, as with the rest of Group C. Also, on the average, Subject K faced one modality problem per draft 1, which was much higher than any of the subjects in Groups A and B.

The other three subjects in Group C encountered increases in modality problems beyond their second drafts, with Subject D facing a three-point rise. This pattern for the modality measure was not typical of Groups A and B. In fact, the frequency of modality problems for Group A was negligible.

DISCUSSION

On its own, each problem pointed out in the corpus may seem minor--for example, the use of <u>the</u> as opposed to <u>a</u>, <u>is</u> in place of <u>can</u>. But collectively, these surface elements serve to fill in the picture of each student's ability to conceive the subject matter in a clear frame of reference or to sort out the ontological status of the object. These microelements give us clues as to where in the process the students encountered difficulties in the understanding, conceptualizing, and expression of the subject matter.

Breakdowns in the students' production processes were also discerned through their syntactic problems. Our focus here was not on isolated errors. Instead, we sought out forms similar to those appearing in other contexts where speech was either the primary or the fall-back mode. We looked for these patterns in a wide spectrum of settings: remedial writing (Krishna, 1975; Carkeet, 1977; Shaughnessy, 1977; Flower, 1990); language typology (Chafe, 1976); writing acquisition (Kress, 1982); sociolinguistics (Wolfram and Fasold, 1974); orality and literacy studies (Bernstein, 1974; Ong, 1982; Beaugrande, 1984), and the historical study of languages (Givón, 1979). The subjects' syntactic problems assumed features characteristic of forms found in these other settings because the freshman writers here and language users reported in these studies shared a similar situation--all of them were caught in the transition between the oral and written modes. When the subjects in our study found the mathematical content too difficult, they could not sustain the cognitive load of simultaneously creating the compact hierarchic structures of formal written language. The asyntactic forms reported in this writing-in-mathematics study and in other research may be called *emergent patterns*: they offer us insight on the linguistic production typical of human beings caught in this transitional state.

Investigating the measures specific to writing in mathematics, modality and representation, allowed us to address questions on the degree of learning that had taken place with each subject by conducting comparisons across drafts and across students. Were crucial connections made? Did consolidation of information occur? At which stage of drafting (i.e., how far into the semester) did these take place?

Reconstructing the multitude of interconnections among the microelements of the text in this connectionist approach allows us to move beyond general prose descriptions of student writing to an empirical account of what characteristic patterns of change might be for particular populations and why these patterns exist.

Strong students (Group A) showed increasing control over their production, with teacher's comments in early drafts merely serving to remind them to clarify and expand their discussions. This group of students barely had any difficulty dealing with modality, and only minimally with reference and representation. That is, they were quite sure about the status of the topic under discussion and its role within a larger framework as well as the meaning of the representations used to characterize these. The only measure averaging about one problem per draft was syntax, which means that the Group A subjects nevertheless did face some difficulty in organizing and articulating their new knowledge.

Average students (Group B) showed greater fluctuations in their performance in terms of these four measures. Modality problems were still low in this group, but increases in the frequency of such problems for some subjects indicate the subjects' lack of certainty about the relationship between their statements and the mathematical reality. If they experienced problems in this basic area, then it would be expected that they would encounter difficulty maintaining a stable discursive framework (reference). Representation also posed a problem, indicating difficulty with the notations used to capture concisely the mathematical concepts (which had yet to be mastered). But the most telling measure is syntax, where the relatively high number of problems (averaging two to three per draft) reveals the students' mental struggle as they tried to put into words what they had not completely understood. Still, on the whole, this group of students was able to control most of these problems by the third draft, as seen in the reduction of their frequency.

As for weak students, the increasing frequencies of problems highlighted their inability to gain control over the subject matter, even with revision. In fact, revision merely revealed more clearly their struggle. This was demonstrated by the large number of syntactic problems and the rise in representation problems (which typically dropped for the other groups). Problems with reference and modality were also much higher.

CONCLUSION

Admittedly, an emergentist-connectionist model, in constructing the interconnections among the microelements of a text and between texts, is laborious work. But if we want to advance beyond abstract prose descriptions of students' writing which lack empirical grounding and applicability beyond the particular setting involved, then we have to develop a research model that can tease out universal patterns from the concrete and the specific. We need a model that incorporates concrete measures which are generalizable, explanatory, and predictive.

Can the model be applied to assessment? Eventually. First, we need to use it to understand how writing development occurs. And above, we have shown that even though the paths of development may vary, they nevertheless follow characteristic patterns for subgroups of the student population.

If we continue to analyze more data, more writers, and more contexts, we will see new patterns of problems and successes emerge. We can then use these insights to guide a more informed and responsive pedagogy within and beyond WAC.

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Table 1

Total Average Frequencies of All Measures: Group A

Subject	Draft 1	Draft 2	Draft 3
A	2.6	1.5	
L	2.2	1.5	
B	3.5	2.2	0.0
G	3.5	1.1	

Note: The average frequencies of each measure for each category (draft 1, 2, 3) were added together to obtain the total average frequencies of all measures for each category.

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Table 2

Average Frequencies of Each Measure: Group A

Subj	Reference			Syntax			Modality			Representation		
	d1	d2	d3	d1	d2	d3	d1	d2	d3	d1	d2	d3
A	0.4	0.6		0.8	0.6		0.0	0.0		1.4	0.3	
L	0.6	0.5		1.0	0.5		0.0	0.0		0.6	0.5	
B	1.0	0.5	0.0	1.3	0.9	0.0	0.2	0.0	0.0	1.0	0.8	0.0
G	1.5	0.6		1.0	0.5		0.0	0.0		1.0	0.0	

Note: For each measure (reference, syntax, modality, representation), the frequency of problems for each draft of each assignment was recorded. The frequencies from all drafts of each category (draft 1, 2, 3) were totaled before dividing the sum by the number of drafts of that category to obtain the average frequency of each measure for each category. Some students submitted more than two drafts per assignment while others did not. Labels d1, d2, and d3 in the table refer to drafts 1, 2, and 3 respectively. Thus, for example, the number under d1 for the reference measure of a subject indicates the average frequency of referential problems in each of her first drafts across the six assignments given.

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Table 3

Total Average Frequencies of All Measures: Group B

Subject	Draft 1	Draft 2	Draft 3
J	3.4	6.1	4.5
C	4.6	3.1	4.0
F	4.6	5.7	3.3
M	6.7	3.5	
H	4.2	1.9	0.9

Note: The average frequencies of each measure for each category (draft 1, 2, 3) were added together to obtain the total average frequencies of all measures for each category.

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Table 4

Average Frequencies of Each Measure: Group B

Subj	Reference			Syntax			Modality			Representation		
	d1	d2	d3	d1	d2	d3	d1	d2	d3	d1	d2	d3
J	1.4	2.0	1.5	1.0	1.6	2.0	0.0	0.5	0.0	1.0	2.0	1.0
C	0.6	0.3	0.0	2.0	0.8	3.0	0.0	0.0	0.0	2.0	2.0	1.0
F	0.8	1.8	0.0	2.0	3.3	2.3	0.3	0.3	0.0	1.5	0.3	1.0
M	0.8	0.0		3.6	3.5		0.5	0.0		1.8	0.0	
H	0.6	0.0	0.3	0.6	0.0	0.0	0.0	0.3	0.0	3.0	1.6	0.6

Note: For each measure (reference, syntax, modality, representation), the frequency of problems for each draft of each assignment was recorded. The frequencies from all drafts of each category (draft 1, 2, 3) were totaled before dividing the sum by the number of drafts of that category to obtain the average frequency of each measure for each category. Some students submitted more than two drafts per assignment while others did not. Labels d1, d2, and d3 in the table refer to drafts 1, 2, and 3 respectively. Thus, for example, the number under d1 for the reference measure of a subject indicates the average frequency of referential problems in each of her first drafts across the six assignments given.

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Table 5

Total Average Frequencies of All Measures: Group C

Subject	Draft 1	Draft 2	Draft 3
I	4.8	4.1	8.0
K	8.9	3.6	
E	7.9	4.5	5.0
D	4.6	3.8	4.3

Note: The average frequencies of each measure for each category (draft 1, 2, 3) were added together to obtain the total average frequencies of all measures for each category.

Table 6

Average Frequencies of Each Measure: Group C

Subj	Reference			Syntax			Modality			Representation		
	d1	d2	d3	d1	d2	d3	d1	d2	d3	d1	d2	d3
I	1.3	0.5	2.0	2.3	3.0	0.5	0.5	0.0	2.0	0.7	0.6	3.5
K	2.0	0.6		3.3	2.0		1.0	0.0		2.6	1.0	
E	1.0	0.5	0.5	3.8	2.5	2.0	1.3	0.0	0.5	1.8	1.5	2.0
D	0.8	0.0	0.0	1.0	0.5	0.3	0.5	0.3	3.0	2.3	3.0	1.0

Note: For each measure (reference, syntax, modality, representation), the frequency of problems for each draft of each assignment was recorded. The frequencies from all drafts of each category (draft 1, 2, 3) were totaled before dividing the sum by the number of drafts of that category to obtain the average frequency of each measure for each category. Some students submitted more than two drafts per assignment while others did not. Labels d1, d2, and d3 in the table refer to drafts 1, 2, and 3 respectively. Thus, for example, the number under d1 for the reference measure of a subject indicates the average frequency of referential problems in each of her first drafts across the six assignments given.

Chart A

Total Average Frequencies of All Measures: Group A

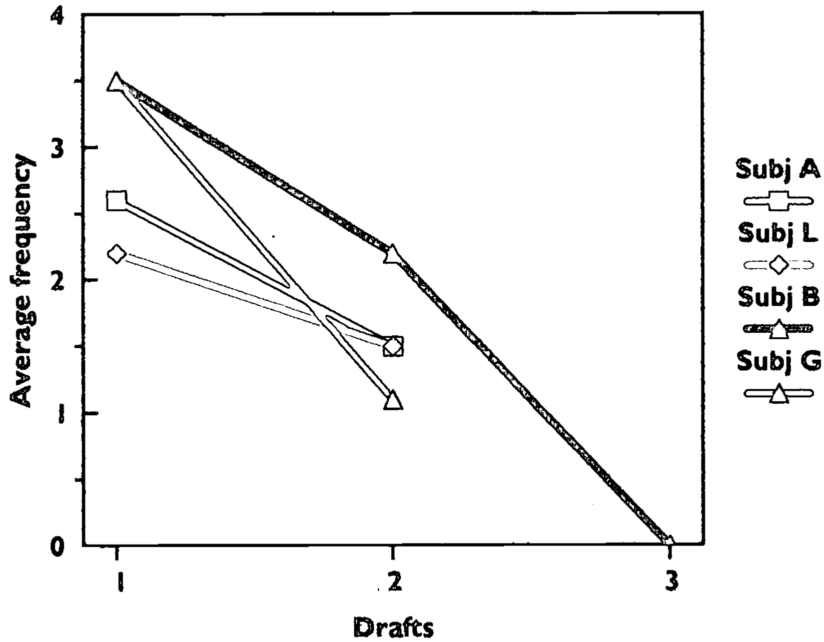

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Chart B

Average Frequencies of Reference Measure: Group B Sample

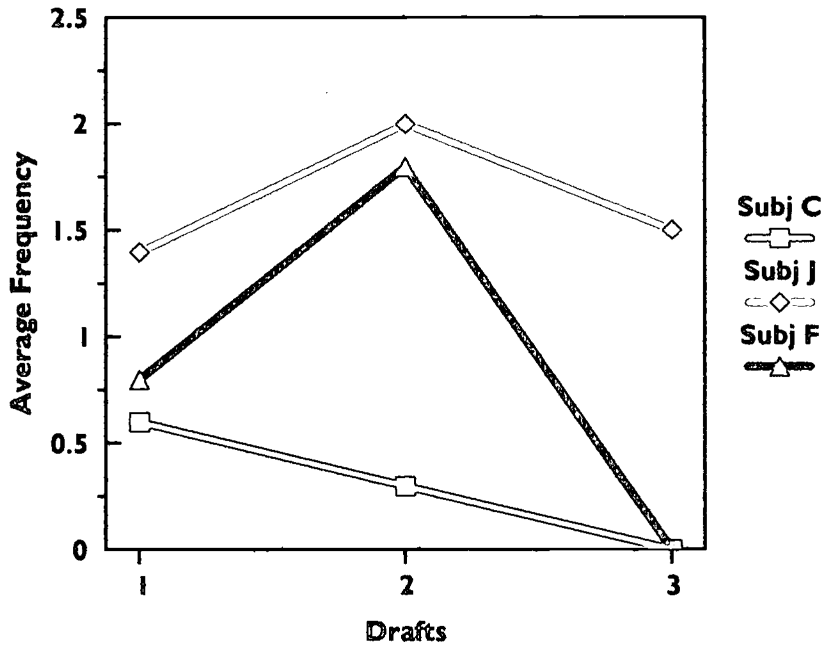

Chart C

Average Frequencies of Syntax Measure: Group B Sample

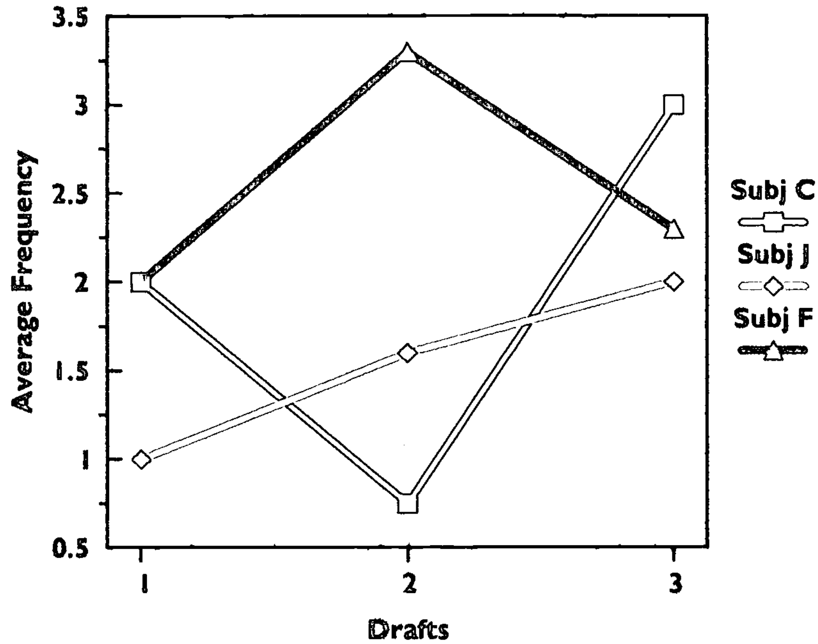

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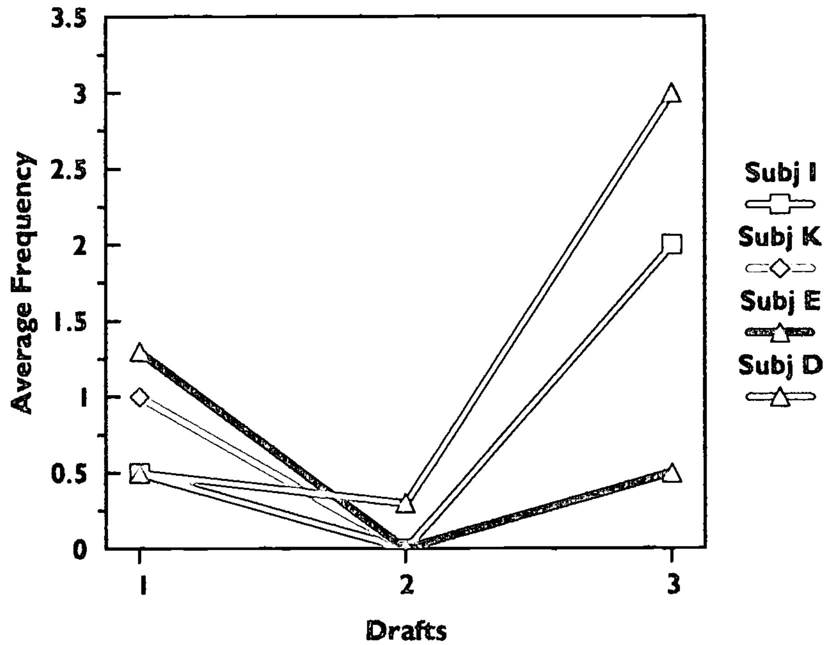
Chart D

Average Frequencies of Modality Measure: Group C



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